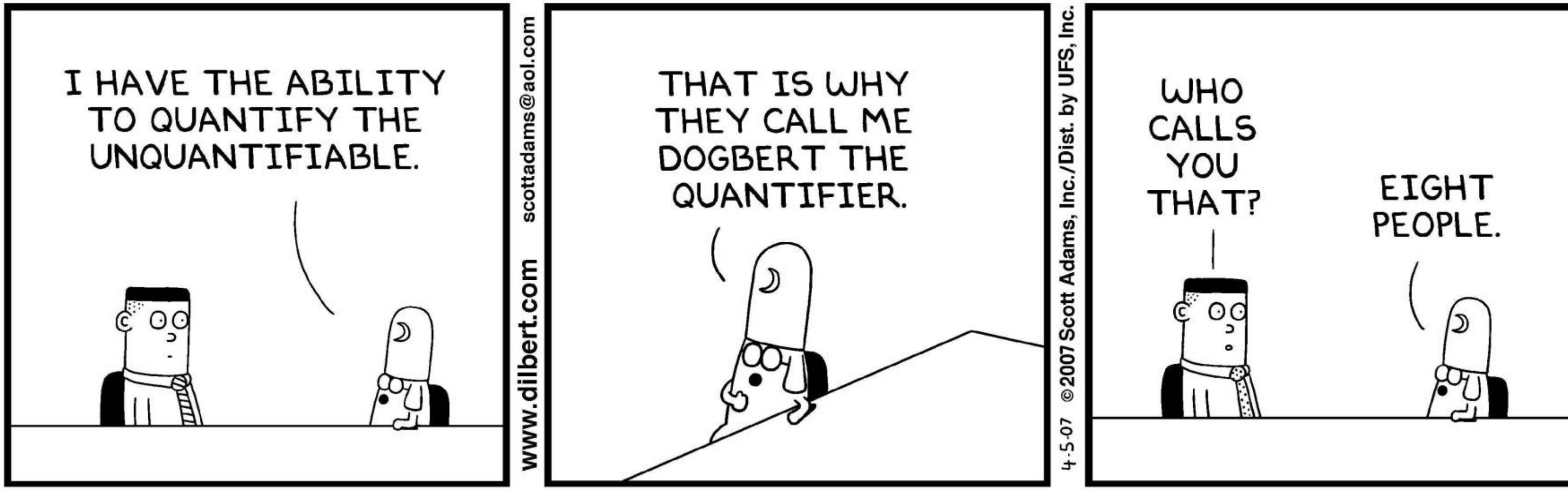
2014 NASA Cost Symposium
August 12-14, 2014 • NASA Langley Research Center

Expert Elicitation of a Maximum Duration using Risk Scenarios

Presented by:

Marc Greenberg
Cost Analysis Division (CAD)
National Aeronautics and Space Administration

A Day in the Life of a Cost Analyst …



How Does A Cost Analyst REALLY Quantify the Unquantifiable?

A. Yell out a cool sounding number with conviction!
B. Divide what's available in your budget by 1, then multiply it by 0.78
C. Apply common estimating methods (e.g., analogy & parametric)
D. Use subject matter expert opinion
E. Incorporate cost risk & uncertainty analysis techniques
F. C, D or E (or any combination of C, D and E)

Outline

- Purpose of Presentation
- Background
  - The Uncertainty Spectrum
  - Five Expert Elicitation (EE) Phases
- Case Study: Estimate Morning Commute Time
  - Establish Framework of Interview Session
  - 1: Direct Input (DI) Method
    - The Risk Reference Table (note: Also used for SB-RRW Method)
  - 2: Scenario Based Relative Risk Ratio (SB-RRW) Method
- Suggested use of DI and SB-RRW Methods in Practice
- Conclusion

Purpose of Presentation

Demonstrate two expert elicitation methods that ...

1. **Model expert's inputs as a triangular distribution**
   - Direct Input (DI) Method
     - Q&A to elicit Min, Most-Likely & Max from expert, and then adjust for expert bias.
   - Scenario Based Relative Risk Weighting (SB-RRW) Method
     - Expert-derived scenario-based factors applied to Most-Likely to estimate Min & Max.
2. **Incorporate techniques to account for expert bias**
   - DI: Q&A elicits likelihood to be below Min & above Max
   - SB-RRW: Use of pairwise comparison helps prevent 'gaming' the outcome
   - For both methods, use of visual aids helps expert calibrate original inputs
3. **Are structured in a way to justify expert inputs**
   - DI: Each response to each question requires a rationale from the expert
   - SB-RRW: Output provides each risk factor's contribution to uncertainty

These two methods are set up so that they are not too complex to be impractical & not too simple to be too subjective.

The Uncertainty Spectrum

No Estimate Required

Total Certainty = **Complete information** **All known**

Specific Uncertainty

Objective Probabilities

Data / Knowledge

- - - - - - - - - - - - - - - - **Partial information** - - - - - - - - - - - - - - - - **Known unknowns**

General Uncertainty

Subjective Probabilities

Expert Opinion / Judgment

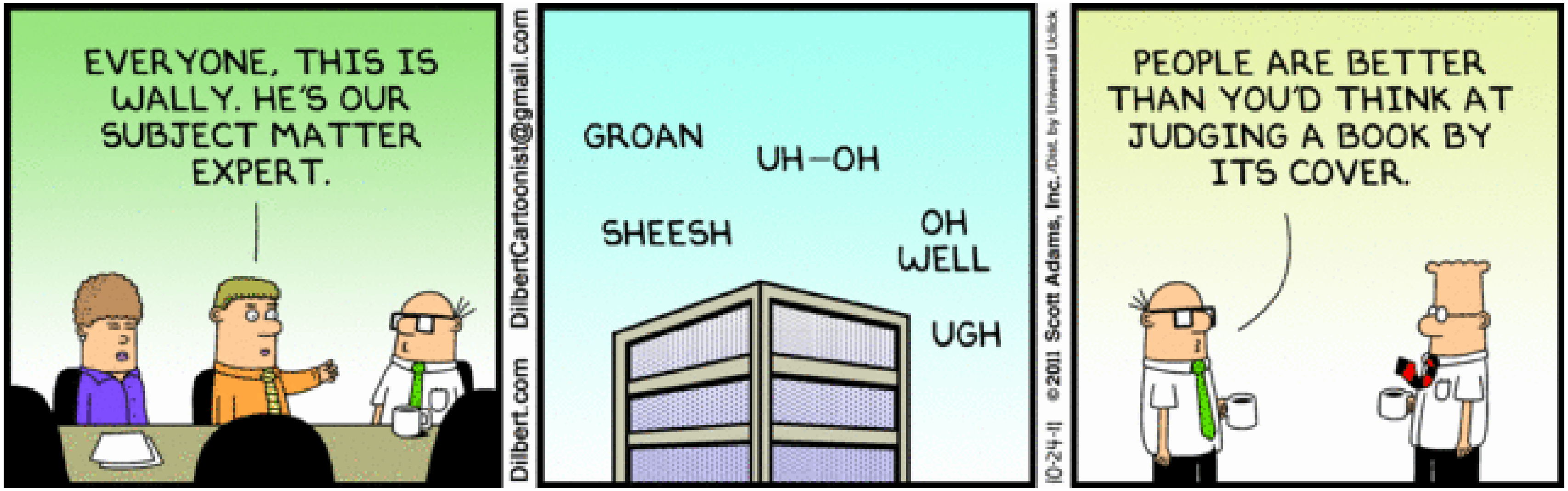
Total Uncertainty = **No information** **Unknown unknowns**

No Estimate Possible

Reference: *Project Management Consulting* by AEW Services, 2001

Expert judgment should only be used when there is (i) lack of time for collection & analysis of historical data, (ii) lack of available historical data or (iii) the design is incomplete

Expert Judgment Definition



Contrary to popular belief, this Dilbert Cartoon does NOT give the best definition of Expert "Judgment" ☺

Try this one instead …

Expert Judgment (for estimating) are value estimates developed solely on the basis of a person's experience & knowledge of the process or product being estimated.

Expert Elicitation (EE) Phases

Expert Elicitation consists of five phases:

(note that Phases 4 & 5 are iterative)

1. Motivating the expert
2. Structuring objective, assumptions & process
3. Training (conditioning) the expert
4. Assessing (encoding) expert's responses
   - Q&A – Expert's experienced-based opinion is elicited
   - Quantitative results w/ documented rationale
5. Verifying encoded values & documentation

This majority of this presentation covers only Phase 4

Example: Estimate Commute Time

- **Why this example?**
  - Fairly easy to find a subject matter expert (SME)
  - It is a parameter that is measurable
  - Most experts can estimate a most likely time
  - Factors that drive uncertainty can be readily identified
  - People general care about their morning commute time!

Assume only Given a Most-Likely Commute = 55 minutes

EE Phases 1 and 2: Framework of Interview

EE Phase 1: Motivating the expert

- Explain the importance & reasons for collecting the data
- Explore stake in decision & potential for motivational bias

EE Phase 2: Structuring objective, assumptions & process

- Must be explicit about what you want to know & why you need to know it
  - *Clearly define variable & avoid ambiguity and explain data values that are required (e.g. hours, dollars, %, etc)*

You should have worked with SME to develop the Objective and up to 6 Major Assumptions in the table below

Objective: **Develop an uncertainty distribution associated with time** (minutes) **it will take for your morning commute starting 1 October 2015.**

Assumption 1: Your commute estimate includes only **morning** driving time

Assumption 2: Period of commutes occur in **FY15** (from 1 Oct 2015 thru 30 Sep 2016)

Assumption 3: Commute time will be measured in **minutes**

Assumption 4: '**Most Likely**' commute time reflects the time expected to occur most often

Assumption 5: The commute 'process' will be **analogous** to the one you've been doing

Assumption 6: Unless prompted by interviewer, do not try to account for extremely rare & unusual scenarios

EE Phase 3: Overarching Interview Process

3. Training (conditioning) the expert

- **Go over instructions for Q&A process**
- **Emphasize benefits of time constraints & iterations**

<u>Instructions</u>: This interview is intended to be conducted in up to 3 iterations. Each iteration should take no longer than 20 minutes.

A. Based on your experience, please answer all interview questions.
B. Once you've completed the questions, review them & take a 15 minute break.
C. If required, use the graphics to assist you to answer select questions again.
D. Your interviewer is also here to assist you at any point during the interview.

<u>Notes on 2nd and 3rd iterations (if needed):</u>

A. The 2nd iteration is intended to be a refinement of your 1st round answers.

- Use lessons-learned from the 1st iteration to assist you in the 2nd iteration.

B. The 3rd iteration is intended to be a refinement of your 2nd round answers.

- Use lessons-learned from the 2nd iteration to assist you in the 3rd iteration.

Estimating Min & Max with DI Method

Direct Input (DI) Method.

The DI Method elicits the Most-Likely, Lowest & Highest values from a subject matter expert (SME) in 'round 1' then revisits these questions with the assistance of graphics and a "risk reference" table.

Pros:

a) Relatively fast/efficient way to use SME opinion to get min, most likely & max
b) Easy to explain to stakeholders and decision-makers
b) Enables SME to iterate using graphics, risk factors and risk scenarios

Cons:

a) SME is required to provide initial estimates of low, most likely and high values
b) DI Method typically must counter SME anchoring to her most likely estimate
 - i.e., DI Method nearly always requires adjustment to account for expert bias
c) Expert must recall (& later explain) duration or cost extremes
d) Risk factors affecting dispersion are described after 1^{st} iteration
e) Takes time to set up "risk reference" table

EE Phase 4: DI Method (iteration 1)

Question 1a and 1b: Expert creates "value-scale" tailored his/her bias …

In the context of your morning commute time …

What probability would you assign to a commute time that's *Very* Unlikely ?

What probability would you assign to a commute time that's *Extre*mely Unlikely ?

Available Selection ofValues to the Expert (shaded cells were selected by expert):

VERY LIKELY	VERY UNLIKELY	EXTREMELY LIKELY	EXTREMELY UNLIKELY
80.0%	20.0%	96.0%	4.0%
82.5%	17.5%	97.0%	3.0%
85.0%	15.0%	98.0%	2.0%
87.5%	12.5%	98.5%	1.5%
90.0%	10.0%	99.0%	1.0%
92.5%	7.5%	99.5%	0.5%
95.0%	5.0%	99.9%	0.1%

EE Phase 4: DI Method *(iteration 1)*

Question 1a and 1b: Expert creates a "value-scale" tailored his/her bias …

*What probability would you assign to a commute time that's **Very Unlikely = 10.0%***

*What probability would you assign to a commute time that's **Extremely Unlikely = 1.0%***

Descriptor	Explanation	Probability	
Absolutely Impossible	No possibility of occurrence	**0.0%**	
Extremely Unlikely	Nearly impossible to occur; very rare	**1.0%**	
Very Unlikely	Highly unlikely to occur; not common	**10.0%**	
Indifferent between "Very Unlikely" & "Even chance"		*30.0%*	*= (10% + 50%)/2*
Even Chance	50/50 chance of being higher or lower	**50.0%**	
Indifferent between "Very Likely" & "Even chance"		*70.0%*	*= (50% + 90%)/2*
Very Likely	Highly likely to occur; common occurrence	**90.0%**	*= 100% - 10%*
Extremely Likely	Nearly certain to occur; near 100% confidence	**99.0%**	*= 100% - 1%*
Absolutely Certain	100% Likelihood	**100.0%**	

Only 2 probabilities needed to be elicited in order to create a Value-Scale that has 9 categories!

EE Phase 4: DI Method *(iteration 1)*

4. Assessing expert's responses (Q&A)

Based upon your experience, please answer #2 - #8:

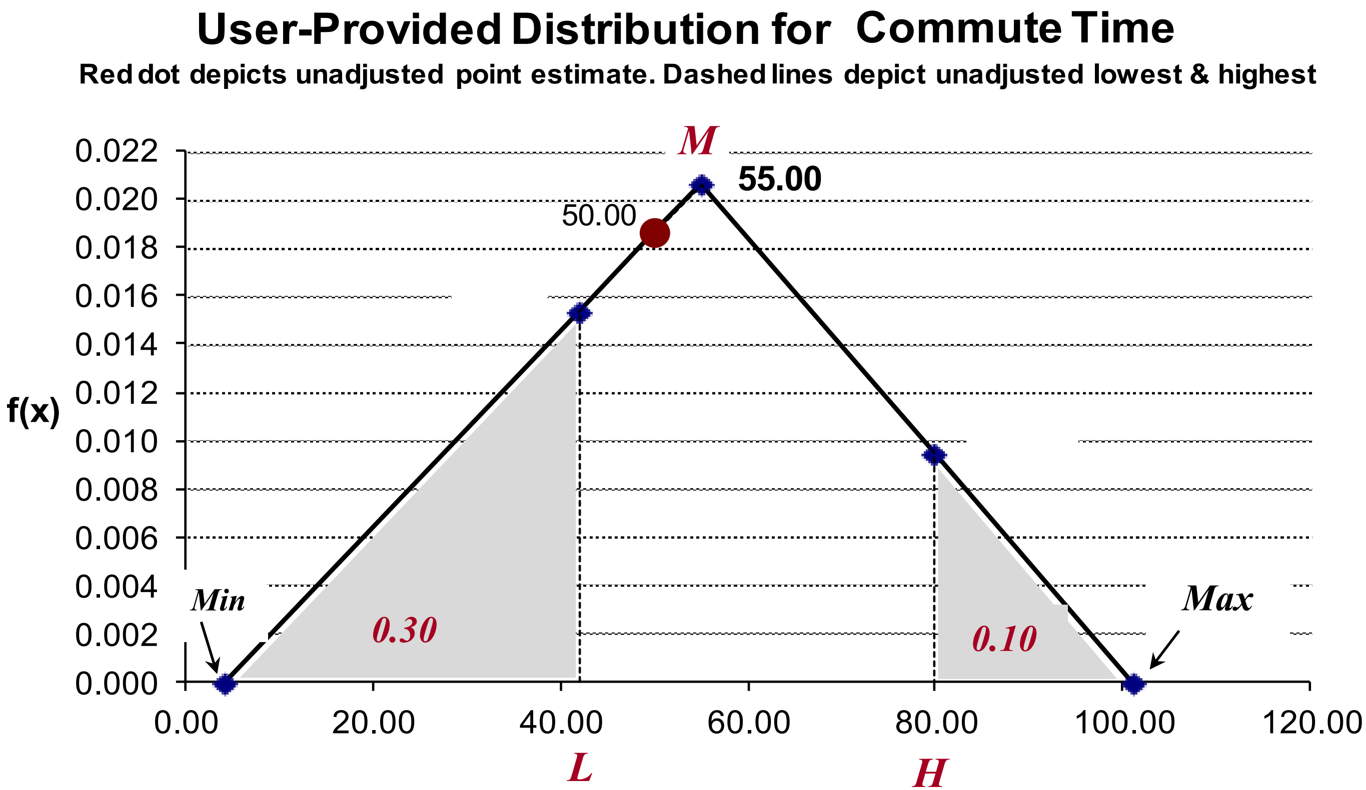
(To assist you, refer to objective & assumptions in slide 9)

2. Describe input parameter (WBS 4): *Morning commute time (in minutes)*
3. What has been your Most Likely commute time in FY14? *50*
4. What will be your Most Likely commute time in FY15? *55 = M*
5. What will be your shortest commute time in FY15? *42 = L*
6. What's the chance an FY15 commute is < 42 minutes? *Indifferent-Low*
   - Discuss & document extremely rare events, unusual scenarios and/or "unknown unknowns"
7. What will be your longest commute time in FY15? *80 = H*
8. What's the chance an FY15 commute is > 80 minutes? *Very Unlikely*
   - Discuss & document extremely rare events, unusual scenarios and/or "unknown unknowns"

This 1st iteration tends to result in anchoring bias on *M*, over-confidence on *L* and *H*, and poor rationale

EE Phase 4: DI Method (iteration 1)

4. Assessing expert's responses (Q&A)



PDF created based upon Expert's responses to Questions 2 through 8.

Take 15 min. break then build "Risk Reference Table" and start Q&A Iteration #2

Given from Expert: L=42, M=55, H=80, p(x<L)=0.30 and p(x>H)=0.10

Calculation of 'true' L and H [a]: L = 1.56 and H = 101.15 … Do these #'s appear reasonable?

(a) Method to solve for L and H presented in "Beyond Beta," Ch1 (The Triangular Distribution)

EE Phase 4: DI Method *(prep for iteration 2)*

- **Prior to starting DI Method - Iteration #2, the SME and Interviewer should work together to create a "Risk Reference Table"**
  - Step 1: Create an Objective Hierarchy
  - Step 2: Brainstorm Risk Factors
  - Step 3: Map Risk Factors to Objective Hierarchy
  - Step 4: Describe / Define the Risk Factors

Note: This Risk Reference Table is also used for SB-RRW

Create Risk Reference Table (Step 1)

Step 1: SME & Interviewer Create an Objective Hierarchy

Q: To minimize commute time, what is your primary objective?

A: *Maximize average driving speed*

Q: What are primary factors that can impact driving speed?

A: *Route Conditions, # of Vehicles on Roads, Mandatory Stops & Driving Efficiency*

Q: Is it possible that other factors can impact driving speed?

A: *Yes … (but SME cannot specify them at the moment)*

Objective	Means These are Primary Factors that can impact Objective
Maximize Average Driving Speed	Route Conditions
	# of Vehicles on Roads
	Mandatory Stops
	Driving Efficiency
	Undefined

The utility of this Objective Hierarchy is to aid the Expert in:

(a) Establishing a Framework from which to elicit most risk factors,

(b) Describing the relative importance of each risk factor with respect to means & objective, and

(c) Creating specific risk scenarios

Create Risk Reference Table (Step 2)

Step 2: SME & Interviewer Brainstorm Risk Factors

Using the Objective Hierarchy as a guide, the SME answers the following:

Objective	Means These are Primary Factors that can impact Objective
Maximize Average Driving Speed	Route Conditions
	# of Vehicles on Roads
	Mandatory Stops
	Driving Efficiency
	Undefined

Q: What are some factors that could degrade route conditions?

A: *Weather, Road Construction, and Accidents*

Q: What influences the # of vehicles on the road in any given morning?

A: *Departure time, Day of the Work Week, and Time of Season (incl. Holiday Season)*

Q: What is meant by Mandatory Stops?

A: *By law, need to stop for Red Lights, Emergency Vehicles and School Bus Signals*

Q: What can reduce Driving Efficiency?

A: *Picking the "Slow Lane", Talking on the Cell Phone and Driving Below Speed Limit*

Create Risk Reference Table (Steps 3 & 4)

Step 3: SME & Interviewer Map Risk Factors to the Objective Hierarchy

Step 4: SME & Interviewer work together to Describe Risk Factors

Objective	Means These are Primary Factors that can impact Objective	Risk Factors These are Causal Factors that can impact Means	Description (can include examples) Subject Matter Expert's (SME's) top-level description of each Barrier / Risk
Maximize Average Driving **Speed**	Route Conditions	Weather	Rain, snow or icy conditions. Drive into direct sun.
		Accidents	Vehicle accidents on either side of highway.
		Road Construction	Lane closures, bridge work, etc.
	# of Vehicles on Roads	Departure Time	SME departure time varies from 6:00AM to 9:00AM
		Day of Work Week	Driving densities seem to vary with day of week
		Season & Holidays	Summer vs. Fall, Holiday weekends
	Mandatory Stops	Red Lights	Approx 8 traffic intersections; some with long lights
		Emergency Vehicles	Incl. police, firetrucks, ambulances & secret service
		School Bus Signals	School buses stopping to pick up / drop off
	Driving Efficiency	Pick Slow Lane	Just check out opening scene of "Office Space" :)
		Talking on Cellphone	On rare occasion, will call someone during commute
		Driving below Speed Limit	Can be due to less work pressure or not feeling well
	Undefined	Undefined	It's possible for SME to exclude some risk factors

This is the most time -intensive part of interview process

It serves as the reference for Iteration #2 and SB-RRW

EE Phase 4: DI Method *(iteration 2)*

4. Assessing expert's responses (Q&A)

Based upon your experience & iteration #1, please answer #1- #8:

(To assist you, refer to objective & assumptions in slide 9 and Risk Reference Table)

1. Do you need to modify the probability value scale? *No*
2. Do you need to re-characterize the input parameter? *No*
3. Do you want to adjust your Most Likely commute time? *No*
4. What will be your Most Likely commute time in FY15? *55 = M*
5. What will be your shortest commute time in FY15? *40 = L*
6. What's the chance an FY15 commute is < 40 minutes? *Extremely Unlikely*
   - Use risk factors in Risk Reference Table to characterize best-case scenarios that could < 40min
7. What will be your longest commute time in FY15? *90 = H*
8. What's the chance an FY15 commute is > 90 minutes? *Indifferent-Low*
   - Use risk factors in Risk Reference Table to characterize worst-case scenarios that could > 90min

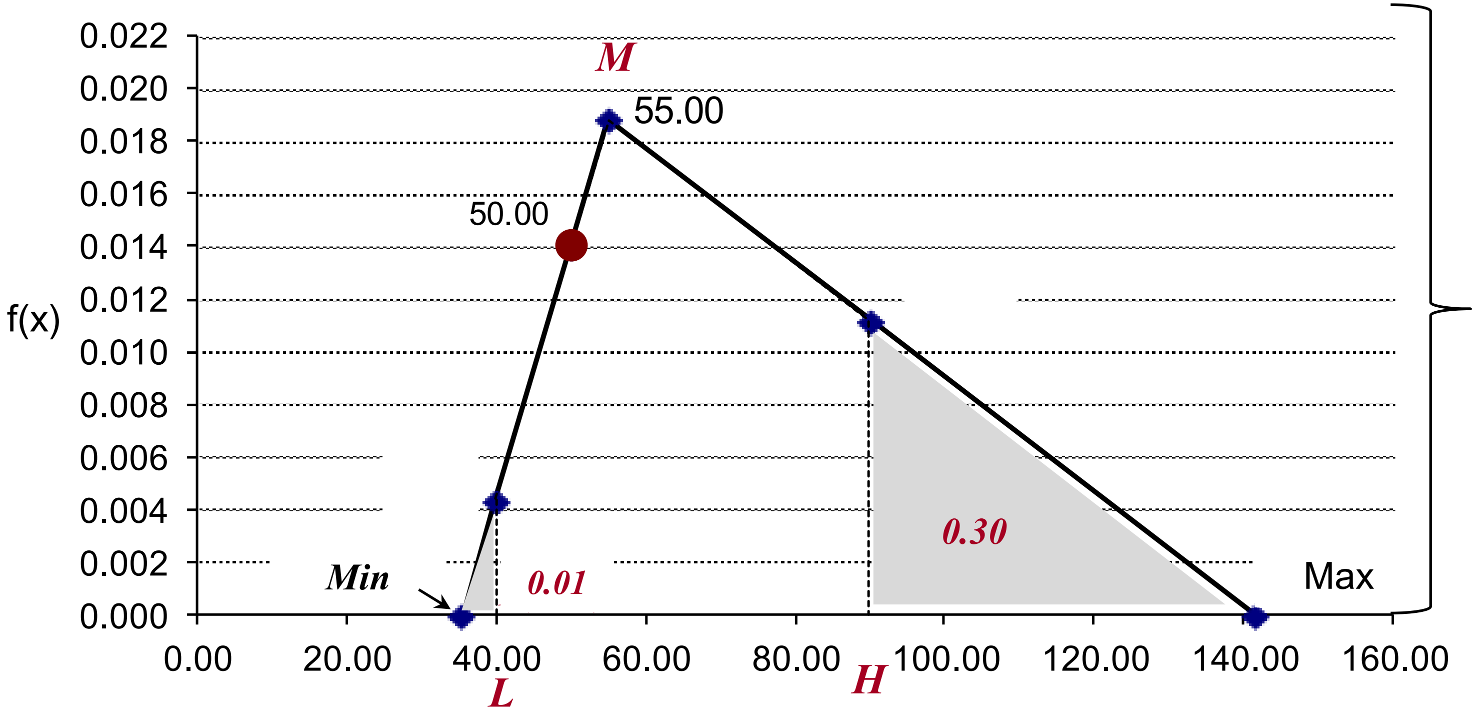
Iteration #1 and Risk Reference Table help improve basis of inputs

EE Phase 4: DI Method (iteration 2)

4. Assessing expert's responses (Q&A)

User-Provided Distribution for Commute Time

Red dot depicts unadjusted point estimate. Dashed lines depict unadjusted lowest & highest



PDF created based upon Expert's responses to Questions 1 through 8.

Given from Expert: L=40, M=55, H=90, p(x<L)=0.10 and p(x>H)=0.30

Calculation of 'true' L and H[(a)]: L = 35.44 and H = 143.92 … Do these #'s appear reasonable?

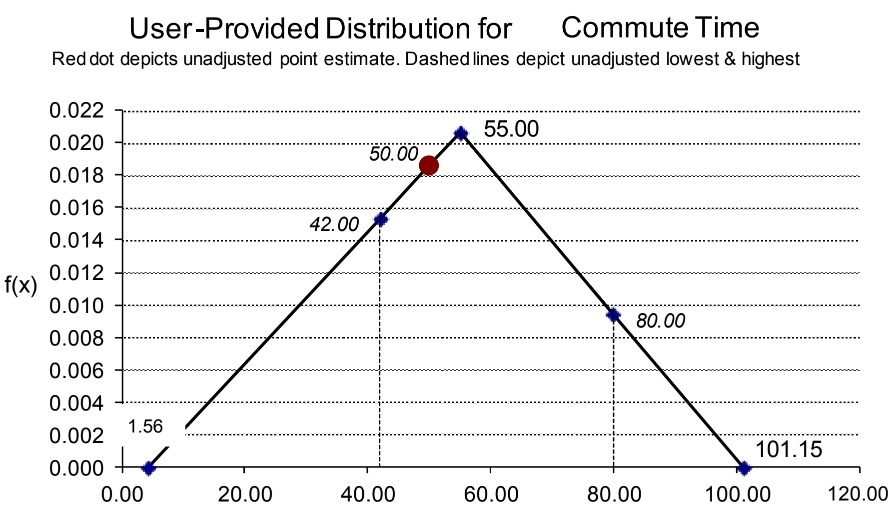
2nd iteration helps "condition" expert to reduce anchoring bias on M, counter over-confidence on L & H, calibrate 'values' & improve rationale.

(a) Method to solve for L and H presented in "Beyond Beta," Ch1 (The Triangular Distribution)

EE Phase 5: DI Method (iteration 2)

5. Verifying encoded values & documentation

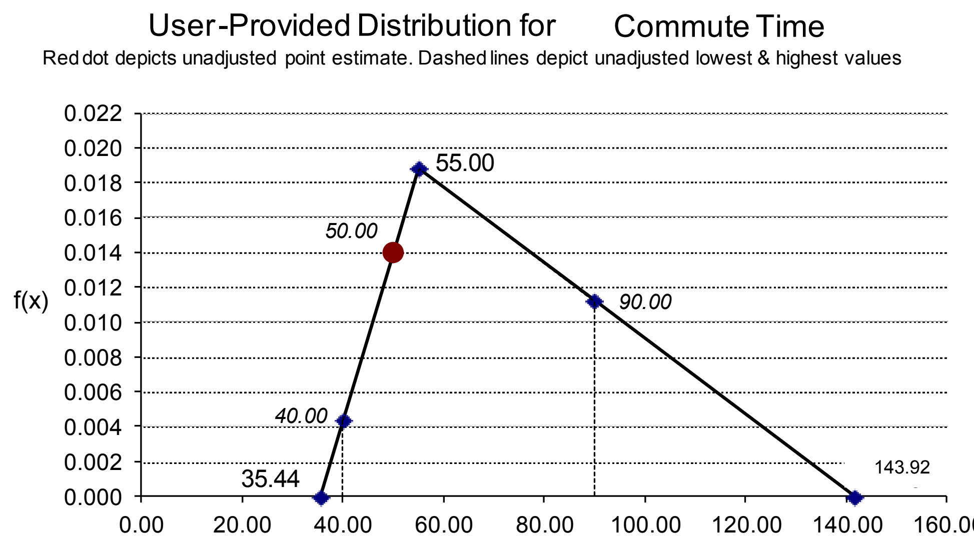
Triangular PDF from Iteration 1



Min =1.56 Max = 101.15

Inputs not necessarily sensitive to risk factors => Optimistic Bias

Triangular PDF from Iteration 2



Min =35.44 Max = 143 .92

Inputs sensitive to weighted risk factors => Minimum -Bias

The 2nd iteration helped elicit a Min that seems feasible and a Max that accounts for worst -case risk factors

Estimating Min & Max with SB-RRW Method [1]

Scenario Based Relative Risk Weighting (SB-RRW) Method.

The SB-RRW Method elicits "risk scenarios" from a subject matter expert (SME) to enable her to describe risks & risk intensities that occur in *typical*, *optimistic* & *pessimistic* scenarios

Pros:

a) SME is not required to provide initial estimates of high & low values
b) Enables SME to iterate using graphics, risk factors and risk scenarios
c) Provides descriptive risk factors that contribute to the uncertainty
d) Provides a means to estimate to what extent each risk factor drives the uncertainty in order to estimate Minimum & Maximum values

Cons:

a) Takes time to set up "risk reference" table
b) Takes time to perform pairwise comparisons (based upon risks)
c) Takes time to develop intensity scale
d) Typically captures only significant known risks

1. A version of a paper by LaserLight Networks, Inc, "Estimating Cost Uncertainty when only Baseline Cost is Available." Their paper is based upon "A Quantification Structure for Assessing Risk-Impact Drivers," R.L Abramson and S.A. Book, 1990

EE Phase 4: SB-RRW (Pairwise Comparison)

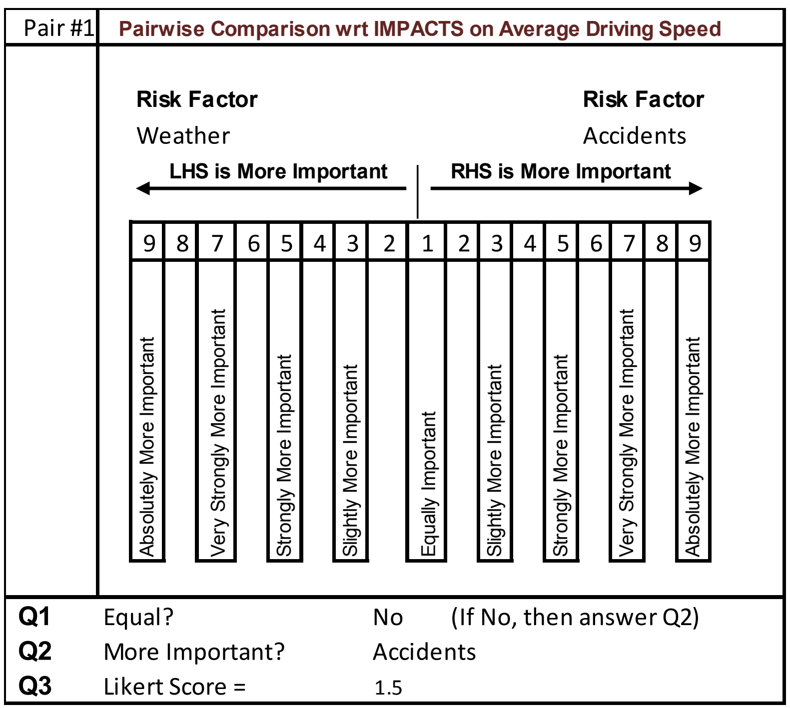
Q : What are the top 6 risk factors that impact your commute time?

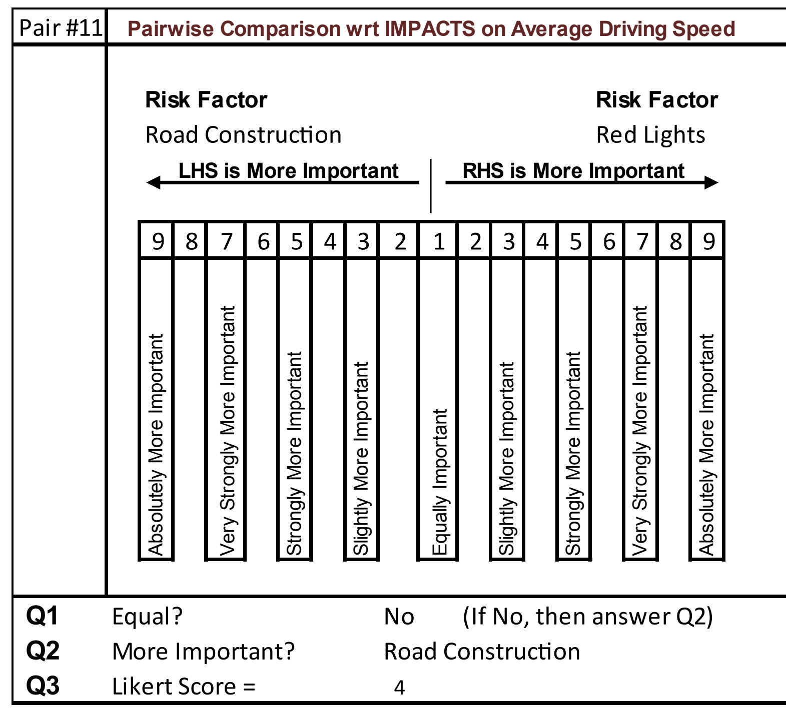
A: Top 3 are … #1. Accidents , #2. Weather and #3. Road Construction

Next 3 are … #4. Departure Time , #5. Red Lights and #6. Seasons & Holidays

Through the use of a simple Pairwise Comparison technique, the Expert can provide relative importance of each risk factor

Because 6 Risk Factors = 15 pairs, use of Visual Aids is recommended (see examples below):





EE Phase 4: SB-RRW (Pairwise Comparison)

Pairwise comparison of risk factors results in the following raw values:

Raw P/W Weighting	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays
Weather	1	2/3	1 1/2	2	4	8
Accidents	1 1/2	1	2	2 1/2	6	9
Road Construction	2/3	1/2	1	2	4	7
Departure Time	1/2	2/5	1/2	1	2	5
Red Lights	1/4	1/6	1/4	1/2	1	2
Season & Holidays	1/8	1/9	1/7	1/5	1/2	1
Sum	**4.0**	**2.8**	**5.4**	**8.2**	**17.5**	**32.0**
Rank	**2**	**1**	**3**	**4**	**5**	**6**

The raw values are normalized to a 100% scale, then summed to Weights per Risk Factor:

Normalized Matrix	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays	Weights
Weather	0.247	0.234	0.278	0.244	0.229	0.250	0.2471
Accidents	0.371	0.352	0.371	0.305	0.343	0.281	0.3371
Road Construction	0.165	0.176	0.185	0.244	0.229	0.219	0.2029
Departure Time	0.124	0.141	0.093	0.122	0.114	0.156	0.1249
Red Lights	0.062	0.059	0.046	0.061	0.057	0.063	0.0579
Season & Holidays	0.031	0.039	0.026	0.024	0.029	0.031	0.0301
Sum	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**

Accidents have the biggest impact (34%) on commute time uncertainty

If Expert is not comfortable with calculated Weights, need to revisit (a) selection of her top 6 risk factors and/or (b) expert-provided Pairwise Comparisons

EE Phase 4: SB-RRW (Intensity Scale & SME Inputs)

Create Intensity Scale for 6 risk factors that impact commute time

Intensity Scale	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays		Value	Normalized
Low	Perfect	None	None	< 7:00AM	No lights	Never	→	1	0.061
Medium-Low	Some wind	Evacuated car on side of road	Shoulder work at 1 location	7:15AM	1 light	Rarely	→	1.5	0.091
Medium	Some rain	1 accident on shoulder	Shoulder work at 2 locations	7:30AM	2 lights	Half of commutes	→	2	0.121
Medium-High	Rain & Wind	2 accidents on shoulder	1 of 3 lane closures	8:00AM	3 lights	More than half of commutes	→	3	0.182
High	Rain & Snow	Accident shutting 1 lane	2 of 3 lane closures	8:15AM	4 lights	>75% of commutes	→	4	0.242
Very High	Snow & Wind	Accident shutting 2 lanes	Temporary road closure	8:30AM	> 4 lights	Nearly Always	→	5	0.303

Expert provides “intensity” levels for each risk factor in each scenario

Scenario Intensities	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays		
Most Likely Intensities	Medium-Low	Low	Medium-Low	Medium	Medium	Medium-Low	→	Typical commute
Optimistic Intensities	Low	Low	Low	Medium-Low	Medium-Low	Low	→	Best case commute
Pessimistic Intensities	Very High	Very High	High	High	High	High	→	Worst case commute

EE Phase 4: SB-RRW (Intensity x Weight = Score)

Using the intensity scale from previous slide, the following inputs …

Scenario Intensities	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays	
Most Likely Intensities	Medium-Low	Low	Medium-Low	Medium	Medium	Medium-Low	→ Typical commute
Optimistic Intensities	Low	Low	Low	Medium-Low	Medium-Low	Low	→ Best case commute
Pessimistic Intensities	Very High	Very High	High	High	High	High	→ Worst case commute

… are replaced with respective normalized values from intensity scale, then multiplied by respective risk factor weights (ref. slide 13) to produce a "Score" for each Scenario …

Risk Factor Weights:

	0.2471	0.3371	0.2029	0.1249	0.0579	0.0301	SCORE
Scenario Intensities	Weather	Accidents	Road Construction	Departure Time	Red Lights	Season & Holidays	Sum Product
Most Likely Intensities	0.091	0.061	0.091	0.121	0.121	0.091	0.0862
Optimistic Intensities	0.061	0.061	0.061	0.091	0.091	0.061	0.0661
Pessimistic Intensities	0.303	0.303	0.242	0.242	0.242	0.242	0.2778

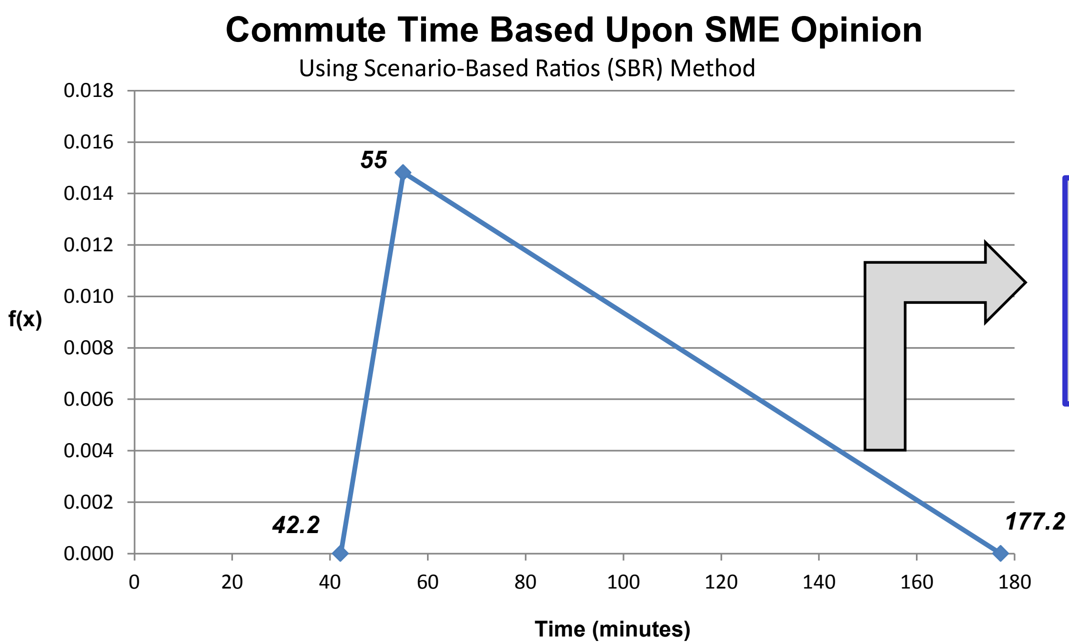
EE Phase 4: SB-RRW (Ratios to get Min & Max)

Use Scores from the 3 scenarios to calculate Ratios wrt Most Likely Score

- Optimistic Score / Most-Likely Score = 0.0661 / 0.0862 = 0.7671
- Pessimistic Score / Most-Likely Score = 0.2778 / 0.0862 = 3.2218

Given a Most Likely Commute of 55 minutes, apply these Ratios to get:

- Minimum Commute Time = 0.7671 x 55 = 42.2 minutes
- Maximum Commute Time = 3.2218 x 55 = 177.2 minutes



If Expert is not comfortable with Min & Max values, need to revisit (a) Intensity scale content and/or (b) expert-provided Intensities

EE Phase 4: SB-RRW (Risk Factor Contributions)

Using weights (slide 13), "Accidents" contribute most to dispersion (46 minutes)

Risk Factor	Weights
Weather	0.2471
Accidents	0.3371
Road Construction	0.2029
Departure Time	0.1249
Red Lights	0.0579
Season & Holidays	0.0301
SUM	**1.000**

% of Total
25%
34%
20%
12%
6%
3%
100%

Impact
33
46
27
17
8
4
135.0

Time Impact due to Realization of Given Risk

Total minutes from Minimum to Maximum

But this is not accounting for impact of "undefined" risk factor.

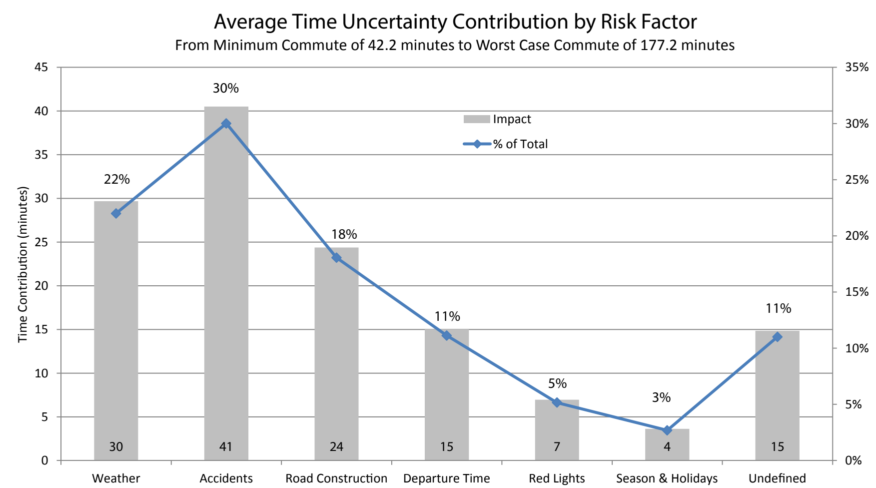
Therefore, Interviewer must ask the Expert:

Q: Suppose you knew the state of all 6 risk factors just prior to your commute. On average within a spread of how many minutes could you estimate your commute time?

A: About 15 minutes

Risk Factor	Impact
Weather	30
Accidents	41
Road Construction	24
Departure Time	15
Red Lights	7
Season & Holidays	4
Undefined	15
SUM	135.0

% of Total
22%
30%
18%
11%
5%
3%
11%
100%



Suggested Use of DI & SB-RRW Methods in Practice

The most critical effort is to create a "Risk Reference Table"

- And it will only serve schedule / cost elements that share these risks & objective
- Can take >2 hours to set up each, but can be used again for other estimates

DI Method takes little time to execute, relying on SMEs ability to recall Min and Max values, then adjust on 2nd iteration

- Like SB-RRW, DI Method does use Risk Reference Table (on 2nd iteration)
- However, if SME cannot sufficiently justify Min & Max, then SB-RRW is preferred

SB-RRW Method takes more time than DI to set-up, primarily because Intensity Scale is customized to specific risk factors

- After which the SME can efficiently select Intensities for each activity or CER (that could be affected by specific risk factors)
- The Pairwise Comparison only needs to be completed one time to get Weights

One method could be used to calibrate results other method

- Example: After applying DI Method to 10 WBS elements, apply SB-RRW on 1 or 2 of these WBS that have largest spread. Then calibrate DI Method using SB-RRW results.

Conclusion

This presentation demonstrated elicitation methods that ...

1. **Modeled expert's inputs as a triangular distribution**
   - Direct Input (DI) Method
     - Q&A to elicit Min, Most-Likely & Max from expert, and then adjust for expert bias.
   - Scenario Based Relative Risk Weighting (SB-RRW) Method
     - Expert-derived scenario based factors applied to Most-Likely to estimate Min & Max.
2. **Incorporated techniques to account for expert bias**
   - DI: Q&A elicits likelihood to be below Min & above Max
   - SB-RRW: Use of pairwise comparison helps prevent 'gaming' the outcome
   - For both methods, use of visual aids helps expert calibrate original inputs
3. **Were structured in a way to justify expert inputs**
   - DI: Each response to each question requires a rationale from the expert
   - SB-RRW: Output provides each risk factor's contribution to uncertainty

So … hopefully … this adds to the conversation on how best to leverage expert judgment in the cost community.

Questions?

Marc Greenberg

202.358.1025

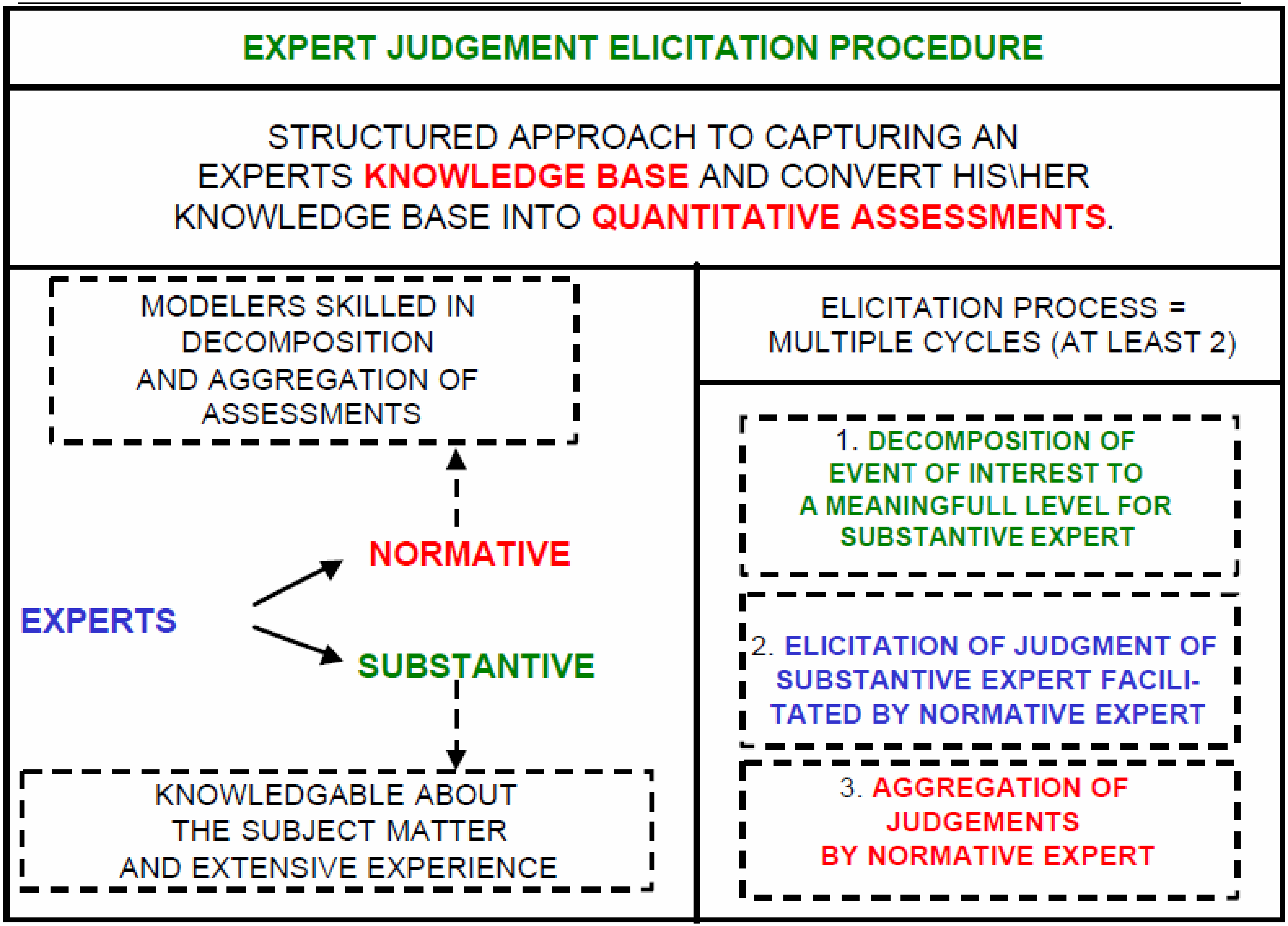
marc.w.greenberg@nasa.gov

Backup Slides

Potential Improvements / Future Work

- General
  - Develop standardized NASA system "Risk Reference Tables"
    - Example: One for Satellites, One for Rockets, One for Aircraft, etc.
    - Note: A system's objective hierarchy may have 2 or more risk factor sets depending on estimate type
  - Develop step-by-step templates for each method (i.e. automate like 1040EZ)
  - Explore other distributions, e.g. Weibull & LogNormal
  - Provide criteria when to elicit mean or median (vs mode)
  - Incorporate methods to combine expert judgments
- DI Method
  - Add questions to enable better "training" of the SME
  - Add questions to help create a Modified Beta-PERT (vs. triangular)
  - Have a way to convert best case & worst case scenarios into probabilities
- SB-RRW Method
  - Develop alternative methods of weighting risk factors
  - Improve intensity tables that depict expert judgment
    - Example: Make less subjective using pairwise comparison method similar to one used to weight risk factors
  - See how SB-RRW may add insight into risks associated w/data-driven CERs

Expert Judgment Elicitation (EE) Procedure



Source: Making Hard Decisions, An Introduction to Decision Analysis by R.T. Clemen

Reasons For & Against Conducting EE

Reasons for Conducting an Expert Elicitation

- The problem is complex and more technical than political
- Adequate data (of suitable quality and relevance) are unavailable or unobtainable in the decision time framework
- Reliable evidence or legitimate models are in conflict
- Qualified experts are available & EE can be completed within decision timeframe
- Finances and expertise are sufficient to conduct a robust & defensible EE

Reasons Against Conducting and Expert Elicitation

- The problem is more political than technical
- A large body of empirical data exists with a high degree of consensus
- Findings of an EE will not be considered legitimate or acceptable by stakeholders
- Information that EE could provide is not critical to the assessment or decision
- Cost of obtaining EE info is not commensurate with its value in decision-making
- Finances and/or expertise are insufficient to conduct a robust & defensible EE
- Other acceptable methods or approaches are available for obtaining the needed information that are less intensive and expensive

Some Common Cognitive Biases

- Availability
  - Base judgments on outcomes that are more easily remembered
- Representativeness
  - Base judgments on similar yet limited data and experience. Not fully considering other relevant, accessible and/or newer evidence
- Anchoring and adjustment
  - Fixate on particular value in a range and making insufficient adjustments away from it in constructing an uncertainty estimate
- Overconfidence (sometimes referred to as Optimistic bias)
  - Strong tendency to be more certain about one's judgments and conclusions than one has reason. Tends to produce optimistic bias.
- Control (or "Illusion of Control")
  - SME believes he/she can control or had control over outcomes related to an issue at hand; tendency of people to act as if they can influence a situation over which they actually have no control.

Four Categories of Uncertainty

	Incident (will / won't)	Variable (range)
Aleatoric (not knowable)	Single point failures 'will the mug break'	Typical accidents 'variable outcomes'
Epistemic (can learn more)	Environmental uncertainties 'the weather'	Most project estimates 'cost & time'

Probability Distributions

Bounded

- Triangular & Uniform
- Histogram
- Discrete & Cumulative
- Beta & Beta-PERT

Unbounded

- Normal & Student-t
- Logistic

Left bounded

- Lognormal
- Weibull & Gamma
- Exponential
- Chi-square

Non-Parametric Distributions: Mathematics defined by the shape that is required. Empirical, intuitive and easy to understand.

Parametric Distributions: Shape is born of the mathematics describing theoretical problem. Model-based. Not usually intuitive.

Of the many probability distributions out there, Triangular & Beta-PERT are among the most popular used for expert elicitation

Triangular Distribution

- **Used in situations were there is little or no data**
  - Just requires the lowest (L), highest (H) and most likely values (M)

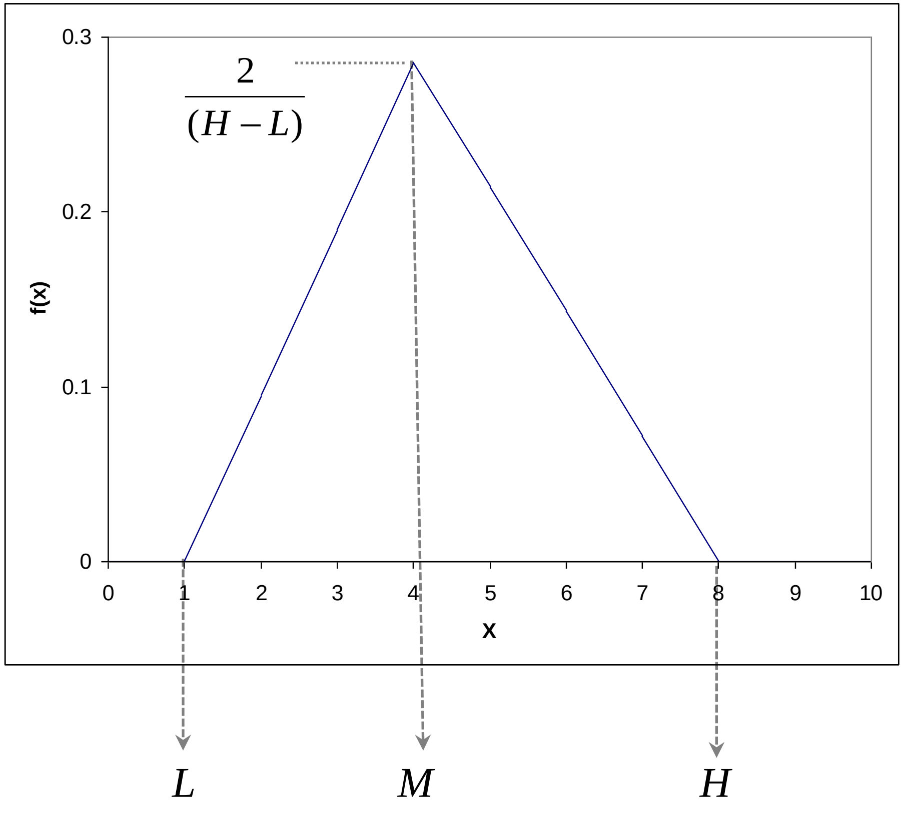
Each x-value has a respective f(x), sometimes called "Intensity" that forms the following PDF:

$$f(x) = \frac{2(x-L)}{(M-L)(H-L)}, \quad L \le x < M$$
$$= \frac{2(H-x)}{(H-M)(H-L)}, \quad M \le x < H$$
$$= 0, \quad \text{otherwise}$$

L, M & H are all that's needed to calculate the Mean and Standard Deviation:

$$\mu = \frac{(L+M+H)}{3}$$

$$\sigma = \sqrt{\frac{(L^2+M^2+H^2-L*M-L*H-M*H)}{18}}$$



Beta Distribution

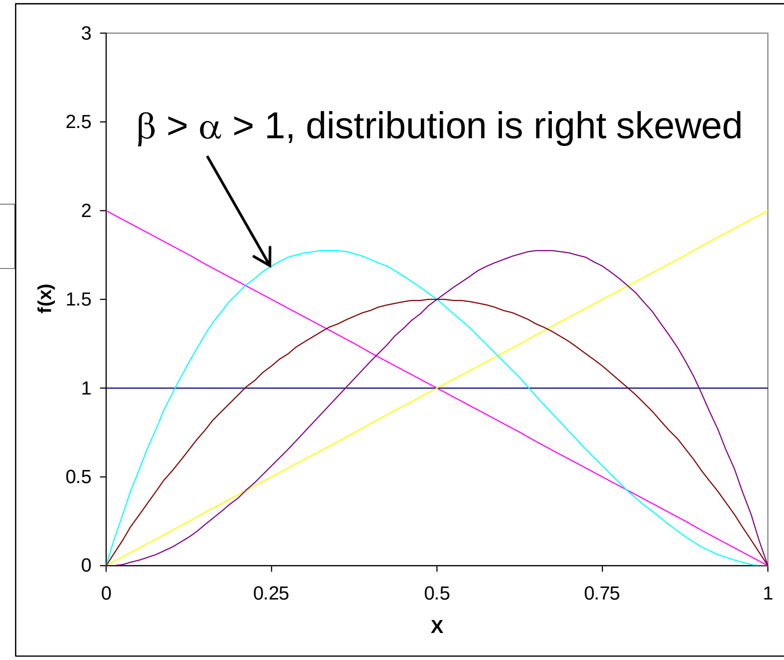
Bounded on [0,1] interval, scale to any interval & very flexible shape

$$f(x) = \left(\frac{1}{H-L}\right)\left(\frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)}\right)\left(\frac{x-L}{H-L}\right)^{\alpha-1}\left(\frac{H-x}{H-L}\right)^{\beta-1} \quad L < x < H \qquad \text{Shape Parameters}: \alpha > 0, \beta > 0$$

$$= 0 \ \text{otherwise}$$

Calculated Gamma values using Excel's GAMMALN function:

$$\Gamma(\alpha) = \text{EXP}[\text{GAMMALN}(\alpha)]$$
$$\Gamma(\beta) = \text{EXP}[\text{GAMMALN}(\beta)]$$



Most schedule or cost estimates follow right skewed pattern. But how do we know α and β? Answer: Beta-PERT Distribution.

Sources: 1. Dr. Paul Garvey, *Probability Methods for Cost Uncertainty Analysis*, 2000
2. LaserLight Networks, Inc, "Beta Modeled PERT Schedules"

Beta-PERT Distribution

Requires lowest (L), highest (H) & most likely values (M)

Use L, M and H to calculate mean(μ) and standard deviation (σ):

$$\mu = \frac{(L + \lambda * M + H)}{\lambda + 2} \qquad \sigma = \frac{(H - L)}{6}$$

Use L, H, μ and σ To calculate shape parameters, α & β:

$$\begin{cases} \alpha = \dfrac{(\mu - L)}{(H - L)} * \dfrac{(\mu - L)(H - \mu)}{\sigma^2} - 1 \\ \beta = \dfrac{(H - \mu)}{(\mu - L)} * \alpha \end{cases} \qquad \text{where } \alpha > 0, \beta > 0$$

α and β are needed to define the Beta Function and compute the Beta Probability Density:

Beta Probability Density Function (as shown in slide 9):

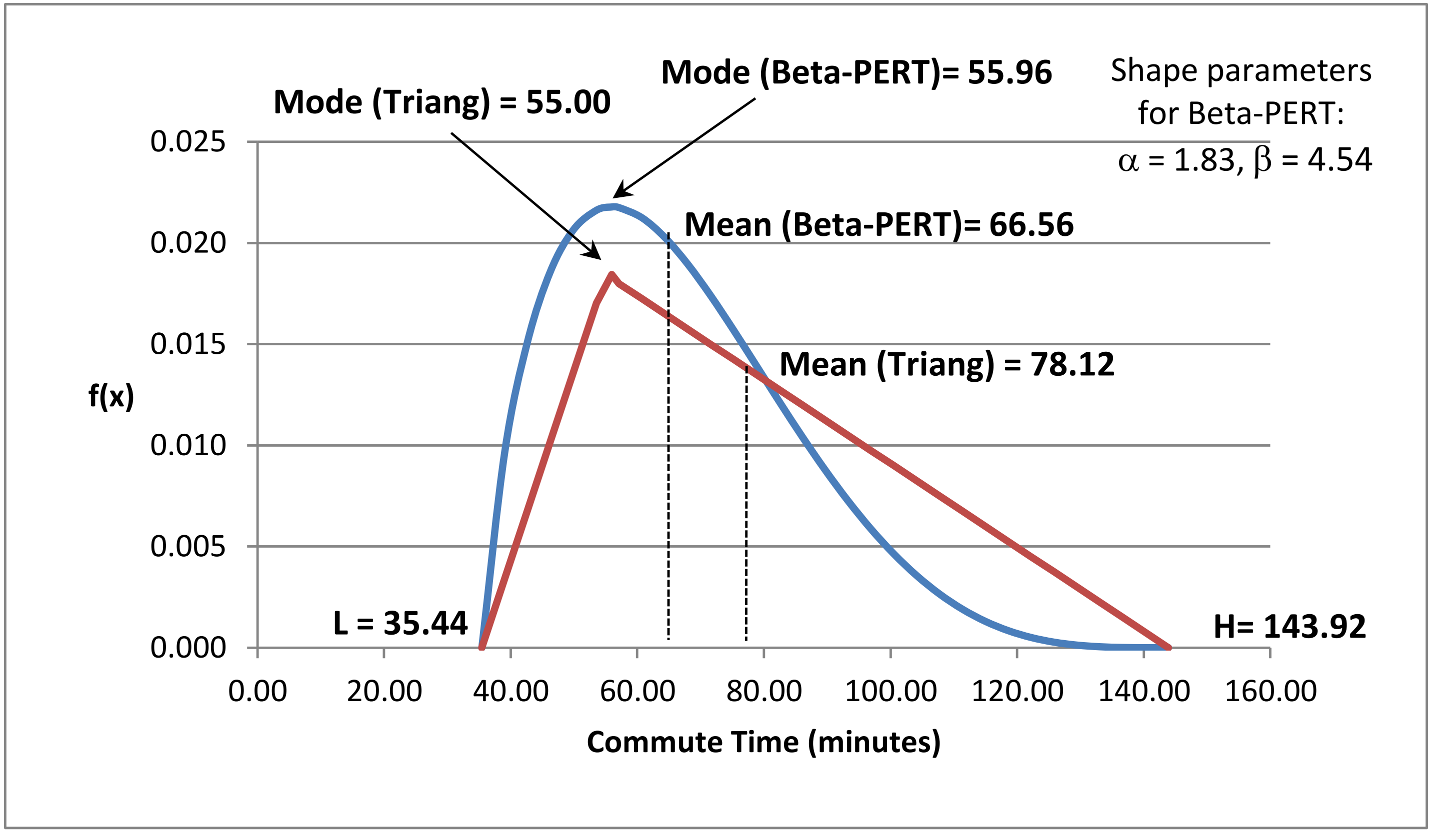
$$f(x) = \left(\frac{1}{H - L}\right)\left(\frac{\Gamma(\alpha + \beta)}{\Gamma(\alpha)\Gamma(\beta)}\right)\left(\frac{x - L}{H - L}\right)^{\alpha - 1}\left(\frac{H - x}{H - L}\right)^{\beta - 1} \quad L < x < H$$

Calculated Gamma values using Excel's GAMMALN function:

$$\begin{cases} \Gamma(\alpha + \beta) = \mathrm{EXP}[\mathrm{GAMMALN}(\alpha + \beta)] \\ \Gamma(\alpha) = \mathrm{EXP}[\mathrm{GAMMALN}(\alpha)] \\ \Gamma(\beta) = \mathrm{EXP}[\mathrm{GAMMALN}(\beta)] \end{cases}$$

Sources: 1. Dr. Paul Garvey, *Probability Methods for Cost Uncertainty Analysis*, 2000
2. LaserLight Networks, Inc, "Beta Modeled PERT Schedules"

Results (Triangular & Beta-PERT)



- **In most cases, Beta-PERT is preferred (vs triangular)**
  - Beta-PERT's mean is only slightly greater than its mode
- **However, triangular would be preferred (vs Beta-PERT) if elicited data seems to depict over-confidence (e.g. H value is optimistic)**
  - Triangular PDF compensates for this by 'exaggerating' the mean value

EE Phase 3: Commute Time (cont'd)

3. Training the expert (continued)

For 2 Questions, you'll need to provide your assessment of likelihood:

Descriptor	Explanation	Probability
Absolutely Impossible	No possibility of occurrence	Values will be defined by SME
Extremely Unlikely	Nearly impossible to occur; very rare	
Very Unlikely	Highly unlikely to occur; not common	
Indifferent between "Very Unlikely" & "Even chance"		
Even Chance	50/50 chance of being higher or lower	
Indifferent between "Very Likely" & "Even chance"		
Very Likely	Highly likely to occur; common occurrence	
Extremely Likely	Nearly certain to occur; near 100% confidence	
Absolutely Certain	100% Likelihood	

Example: Assume you estimated a "LOWEST" commute time of 20 minutes.

Your place a value = 10.0% as the probability associated with "Very Unlikely."

Therefore:

a) You believe it's "VERY UNLIKELY" your commute time will be less than 20 minutes, and

b) This is equal to a 10.0% chance that your commute time would be less than 20 min.